Verification of gamma-nuclear reactions in G4.

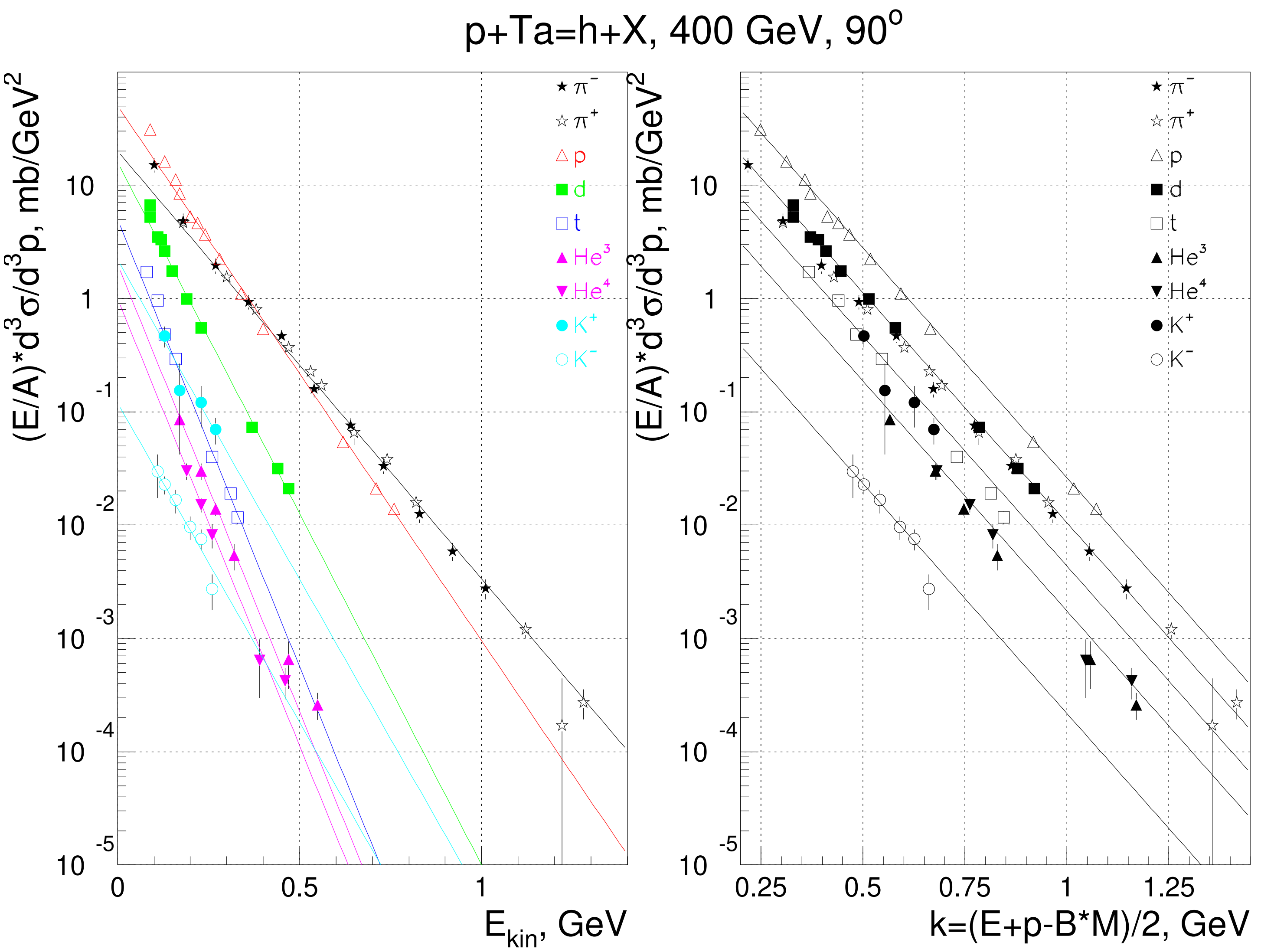
Mikhail Kosov, G4 Physics Verification and Validation

July 19, 2006

1. Test19 as a test facility for gamma-nuclear physics in Geant4.
2. The “photon” subdirectory for neutron production in GDR region.
3. The “gamma” subdirectory for the 60-150 MeV energy region.

CHIPS gamma-nuclear.

- CHIPS gamma-nuclear does not have alternatives in G4 Physics and now (starting G4.8.1) is included in all Recommended Physics Lists;
- There are a GHAD implementation of CHIPS (only for γ and e) and a native CHIPS G4QCollision process covering γ, e, μ, τ reactions;
- The unique approximation of cross-sections of photo-nuclear interaction for all energies (EPJ A14(2002)377) is used;
- The projectile photon is absorbed by a parton (not by a nucleon), and the forward parton defines the angular distribution of fragments;
- The invariant cross-sections of different fragments have the same shape if they are presented as a function of a $k = \frac{T+p}{2}$ variable;
- The k variable is the energy of the hard hadronizing parton;



p+Ta=h+X, 400 GeV, 90°
(E/A)*d³σ/d³p, mb/GeV²
E_kin, GeV
k=(E+p-B*M)/2, GeV
π⁻
π⁺
p
d
t
He³
He⁴
K⁺
K⁻
10
1
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
0
0.5
1
0.25
0.5
0.75
1
1.25

testing of CHIPS gamma-nuclear.

- geant4/test/test19 contains CHIPStest executable and two test subdirectories: "photon" (GDR) and "gamma" (below π threshold);
- The kumac-files in subdirectories create a chipstest.in input file and use the CHIPStest executable to fit the experimental data.
- The chipstest.in is a one-line file which contains a handful parameters of CHIPS, projectile PDG, target PDG, and an incident energy (MeV);
- Results of simulation are saved in the ASCII file, which is converted to ntuple and analyzed by the kumac-file;
- Each subdirectory contains files with data which are used by the kumac file to make a comparison picture (one kumac = one picture);
- The CHIPStest method has an old history and a big help in its development was made by Pavel Degtyarenko from JLab.

Non-relativistic evaporation package in CHIPS

CHIPS considers ultra-relativistic phase space of 3D partons:

$$\Phi_n(E) = \int \delta(\sum_{i=1}^{n} E_i - E)\, \delta^3(\sum_{i=1}^{n} \vec{p}_i) \prod_{i=1}^{n} \frac{d^3\vec{p}_i}{2E_i} \propto s^{n-2},$$

$$\frac{dN}{pdE} \propto \left(1 - \frac{2k}{\sqrt{s}}\right)^{n-2}.$$

Non-relativistic phase space of protons and neutrons (no fragments):

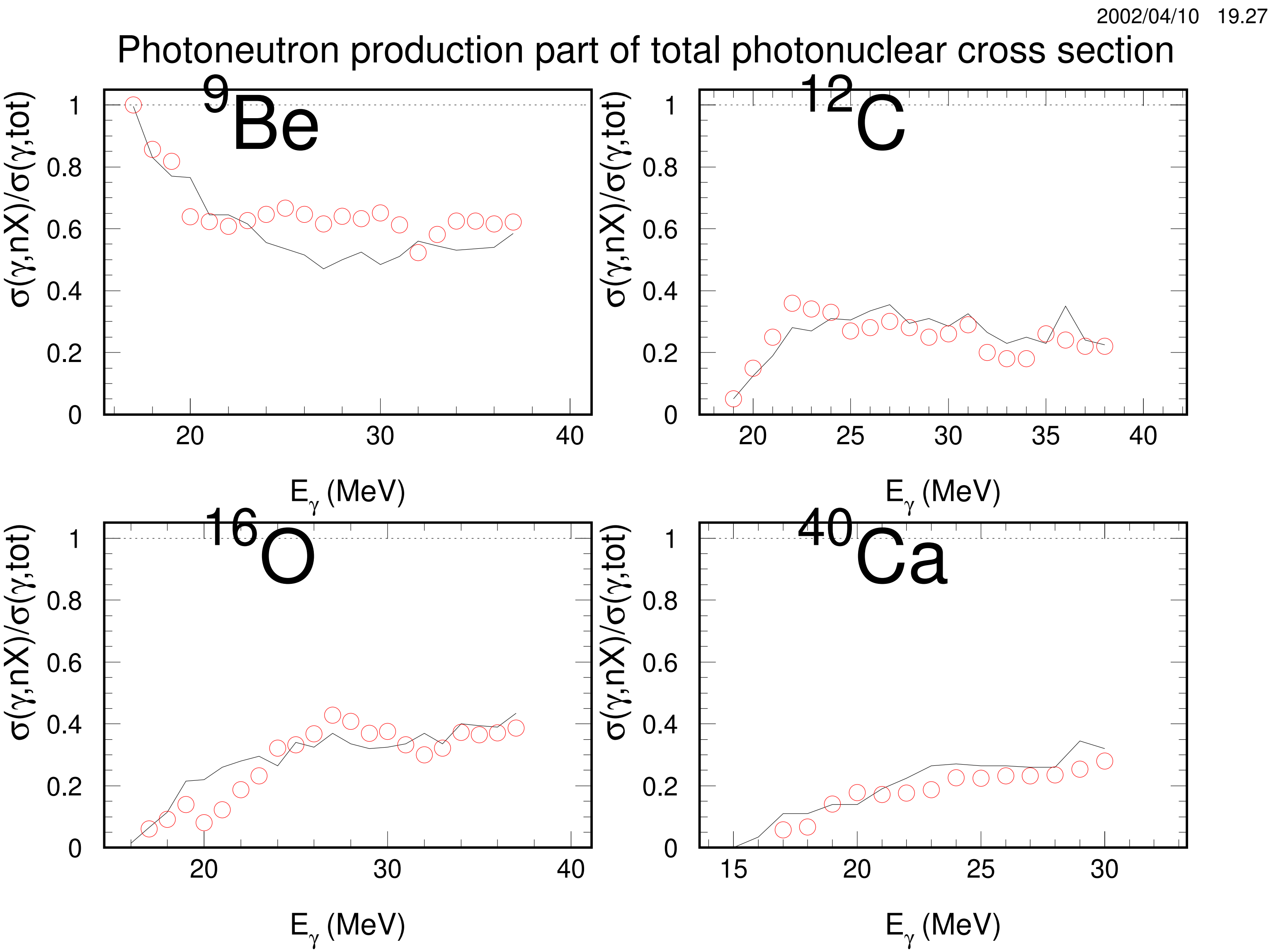
$$\tilde{\Phi}_n(W_n) = \int \tilde{\Phi}_{n-1}(W_{n-1}) \cdot \delta(W_n - W_{n-1} - T)\sqrt{T} dT\, dW_{n-1} \propto W_n^{\frac{3}{2}n - \frac{5}{2}}$$

$$\frac{dN}{\sqrt{T} dE} \propto \left(1 - \frac{T}{W_n}\right)^{\frac{3}{2}n-4}, \;\; W_n\ is\ total\ energy\ of\ n\ nucleons.$$

$$W_A = U \cdot A + E_{\text{excitation}}, \;\; U = 1.7\ MeV\ (an\ internal\ parameter).$$

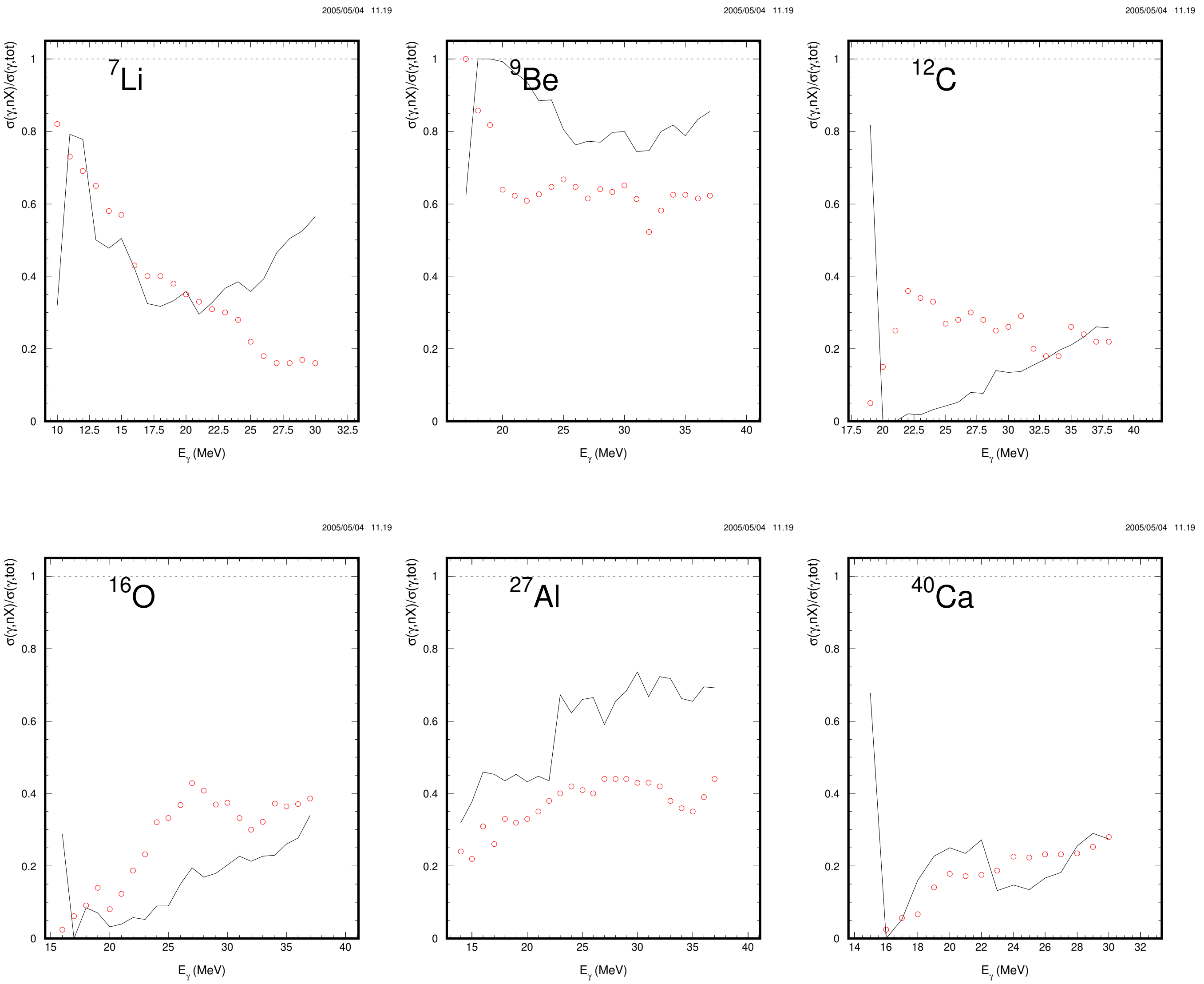
γA in the GDR region ("photon" subdirectory).

- Relative neutron production near threshold is used for the test;
- After the quark level hadronization (Quark Exchange) is exhausted, the non-relativistic evaporation package of CHIPS starts;
- The results of simulation are worse now because the modern nuclear masses data base of CHIPS was changed (because of the energy/momentum conservation) to the old Geant4 data base;
- Relative neutron production is very sensitive to nuclear masses;
- The CHIPS nuclear fragmentation code is the same for gamma-nuclear, hadron-nuclear, stopping, and multi-quasmon fragmentation in QGSC/FTFC, so regression testing ought to be done;
- The "fast and dirty" threshold solution must be removed.



2002/04/10 19.27
Photoneutron production part of total photonuclear cross section
^{9}Be
^{12}C
^{16}O
^{40}Ca
σ(γ,nX)/σ(γ,tot)
E_γ (MeV)
0
0.2
0.4
0.6
0.8
1
15
20
25
30
35
40

Verification of gamma-nuclear reactions in G4.

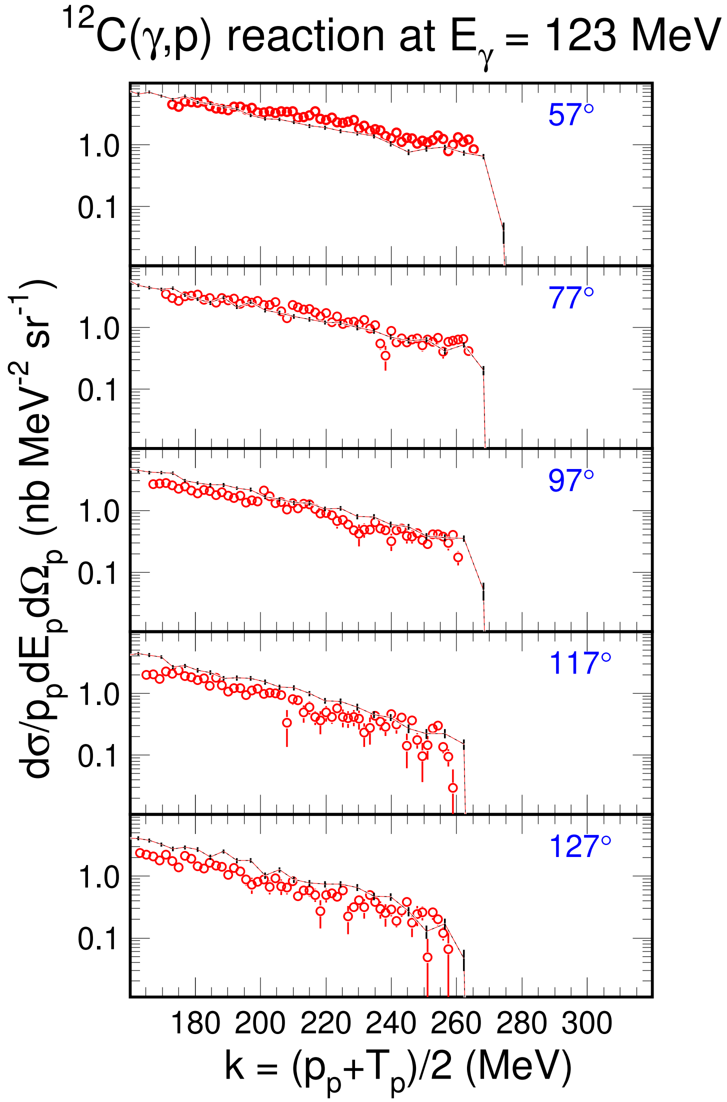


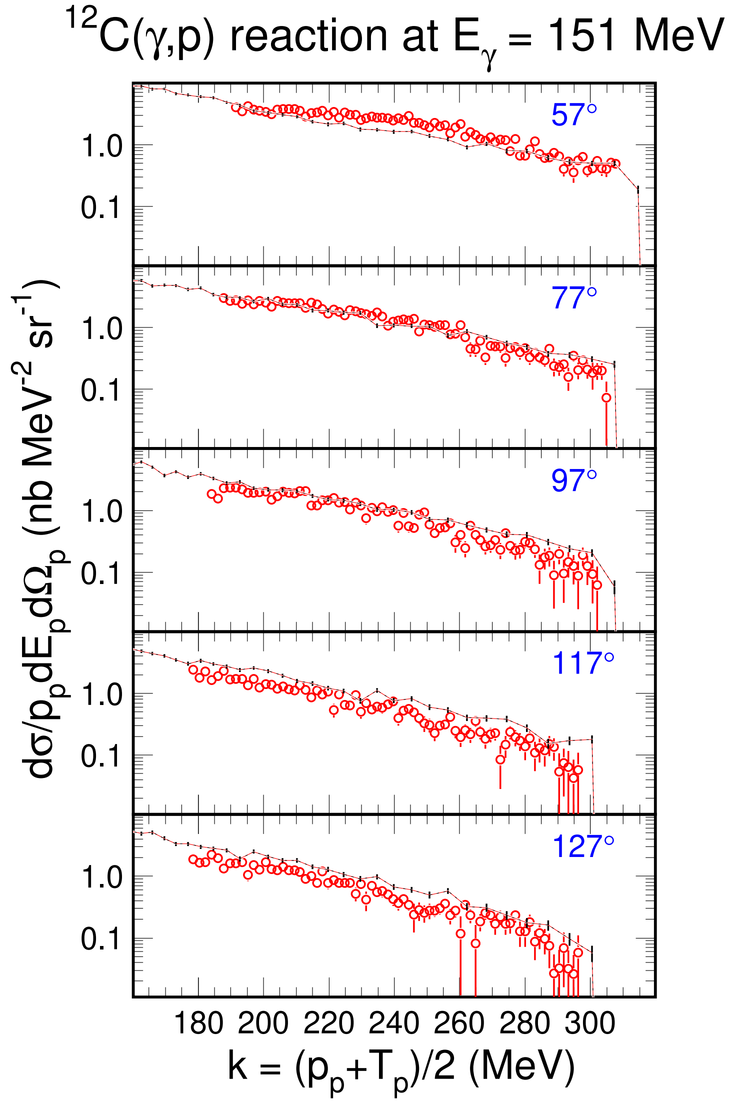
γA below π meson threshold ("gamma" subdirectory).

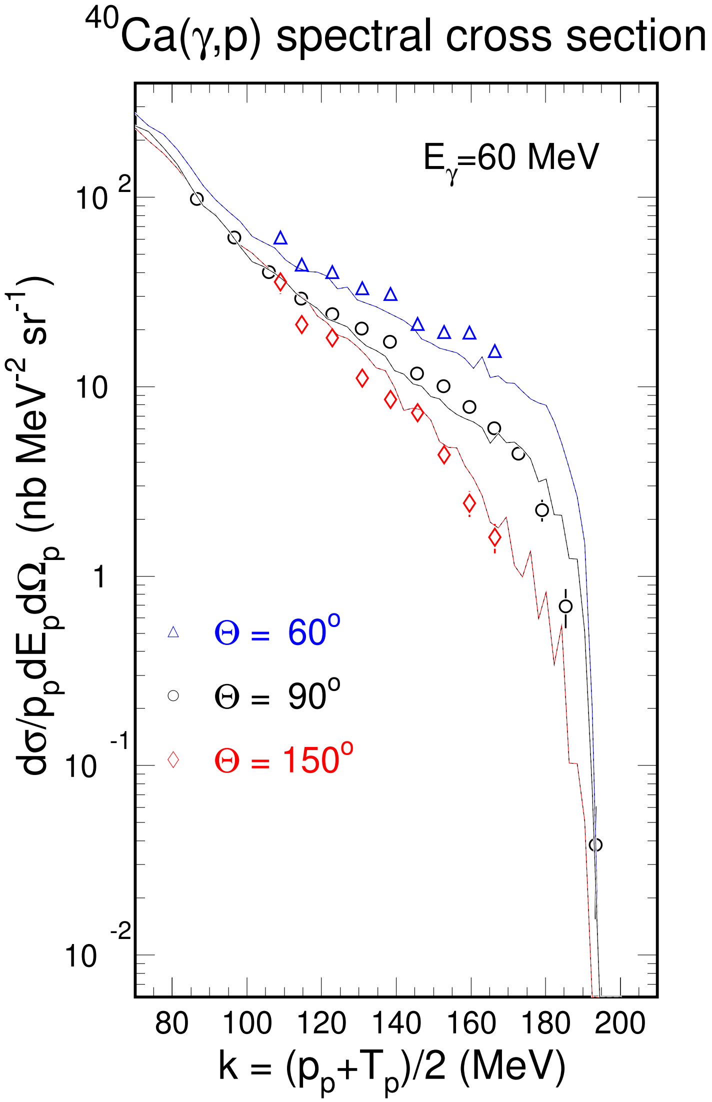
Published in Eur. Phys. J. A9 (2000) 411, and 421.

- Spectra of protons and deuterons are used for the test;
- The cross-section values are not taken from the G4 class (put by hand);
- The angular dependence, which can be a problem for the alternative simulation models (precompound, cascade), is reproduced;
- The energetic part of the spectra is temporary overestimated, but it can be corrected when the hadron-nuclear applications are tuned;
- The test is improved by adding the deuteron spectrum, which is a challenge for the precompound like models;
- More comparison with data are needed above the π meson threshold;
- One more test is going to be prepared for a few hundred MeV.

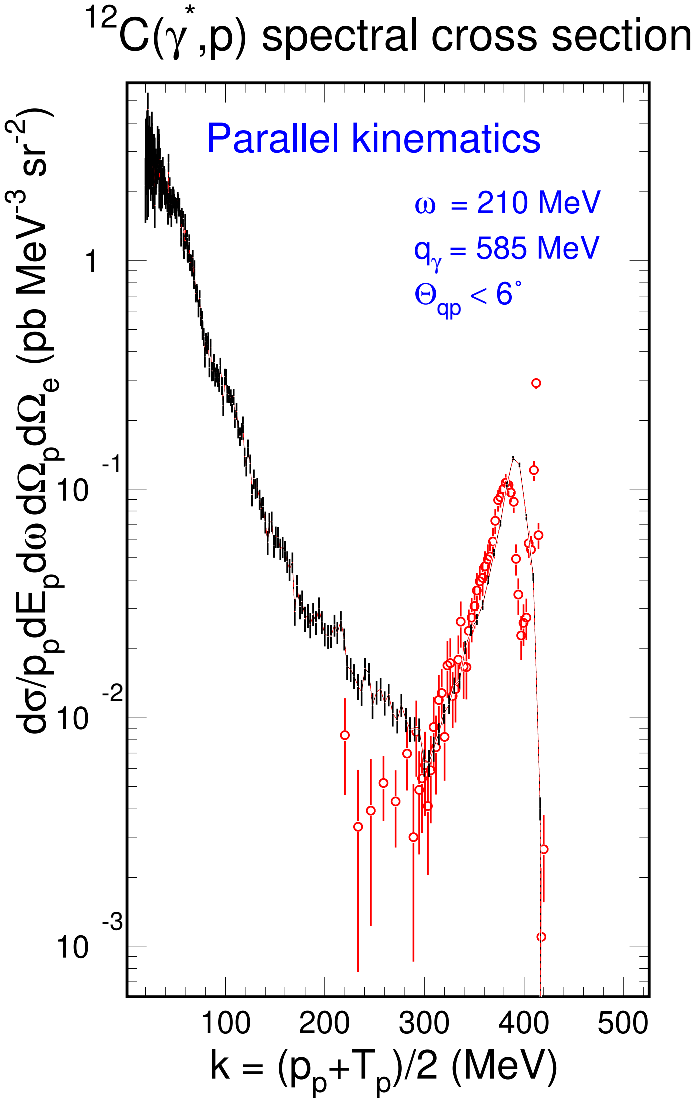
Verification of gamma-nuclear reactions in G4.



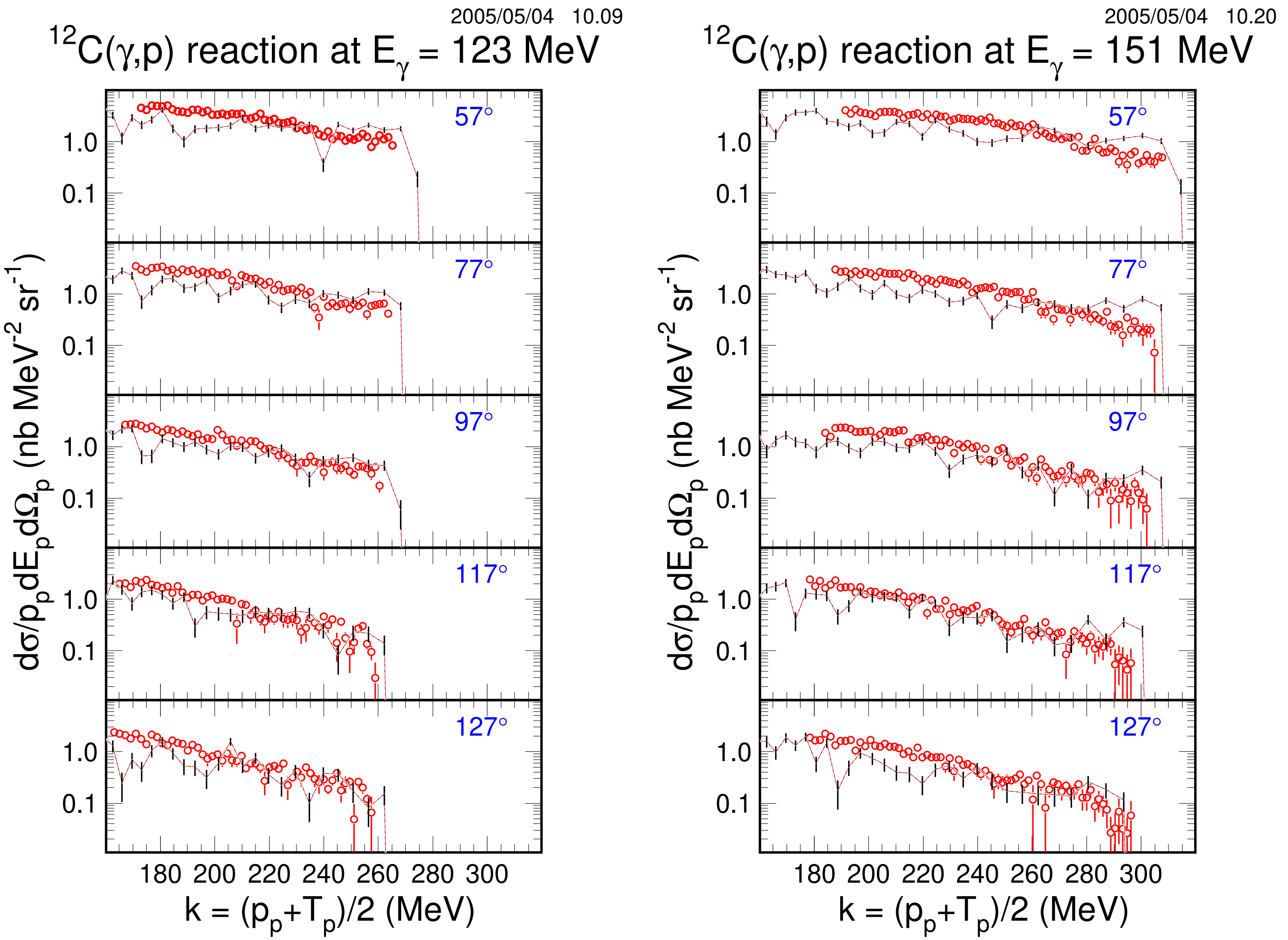


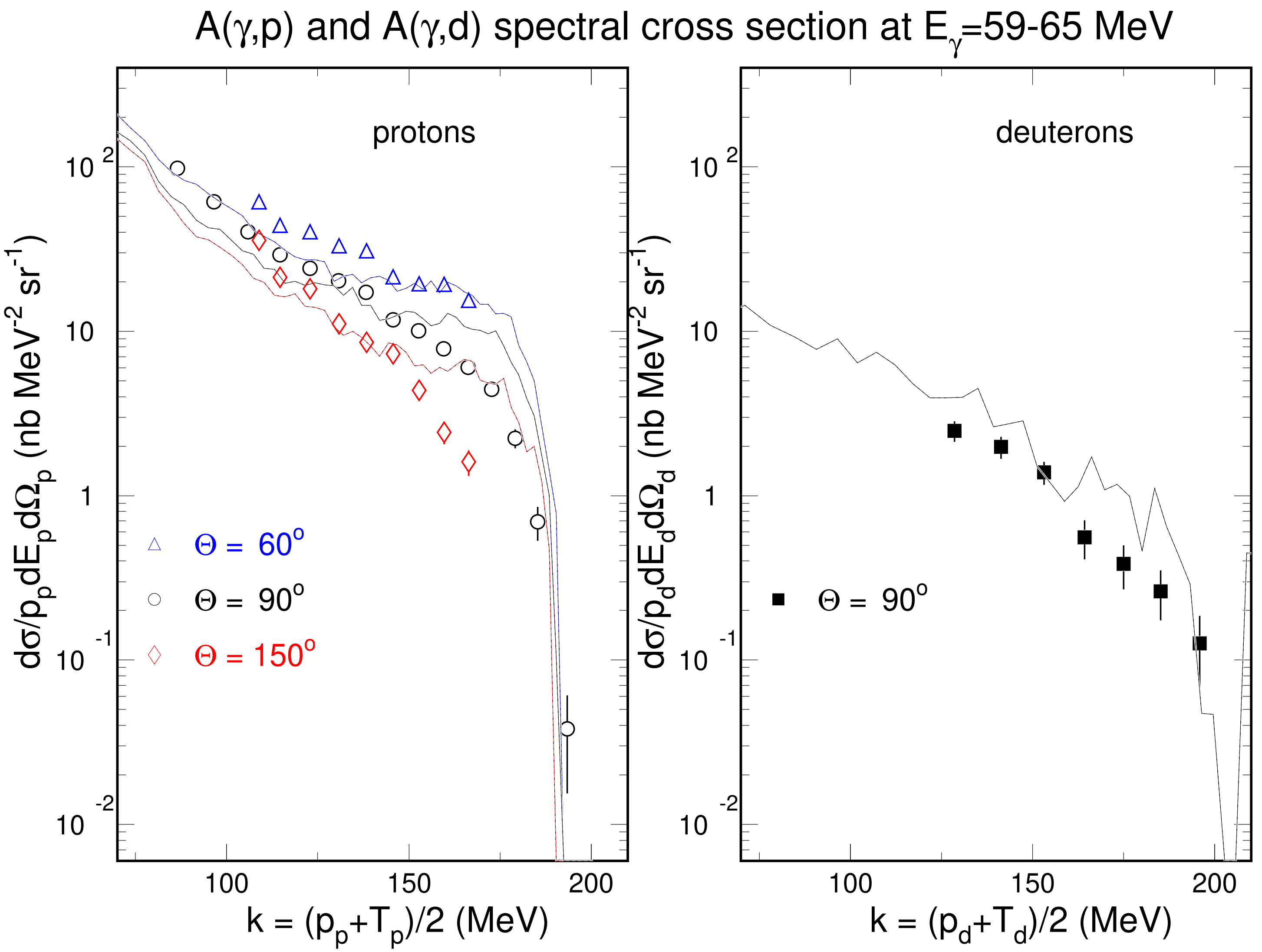


^{40}Ca(γ,p) spectral cross section
E_γ=60 MeV
$d\sigma/p_p dE_p d\Omega_p$ (nb MeV^{-2} sr^{-1})
Θ = 60°
Θ = 90°
Θ = 150°
k = $(p_p+T_p)/2$ (MeV)



^{12}C(γ*,p) spectral cross section
Parallel kinematics
ω = 210 MeV
q_γ = 585 MeV
$\Theta_{qp} < 6^\circ$
$d\sigma/p_p dE_p d\omega d\Omega_p d\Omega_e$ (pb MeV^{-3} sr^{-2})
k = $(p_p+T_p)/2$ (MeV)


2005/05/04 10.09
$^{12}C(\gamma,p)$ reaction at E_γ = 123 MeV
57°
77°
97°
117°
127°
1.0
0.1
$d\sigma/p_p dE_p d\Omega_p$ (nb MeV^{-2} sr^{-1})
180 200 220 240 260 280 300
k = $(p_p+T_p)/2$ (MeV)
2005/05/04 10.20
$^{12}C(\gamma,p)$ reaction at E_γ = 151 MeV


A(γ,p) and A(γ,d) spectral cross section at Eγ=59-65 MeV
protons
deuterons
dσ/ppdEpdΩp (nb MeV-2 sr-1)
dσ/pddEddΩd (nb MeV-2 sr-1)
Θ = 60°
Θ = 90°
Θ = 150°
Θ = 90°
k = (pp+Tp)/2 (MeV)
k = (pd+Td)/2 (MeV)
10^2
10
1
10^-1
10^-2
100
150
200

Conclusion

- The unique approximation of gamma-nuclear cross-sections is made;
- CHIPS model can fit angular dependence of nuclear spectra even at lowest energies of photons, which is a problem for other models;
- CHIPS provides spectra up to the kinematic limit of the reaction;
- CHIPS can give a reasonable branching for different exclusive channels starting from the very threshold of photo-nuclear reactions;
- The normalization by total cross-sections in test19 must be added;
- Photo-nuclear tests for higher photon energies must be added;
- For the low energy tests the exact nuclear masses values are very important, so these values must be improved in Geant4;
- A performance test (all energies and all targets) must be done.